AFRL-IF-RS-TM-2000-3
In-House Technical Memorandum
September 2000

A GRAPHICALLY BASED TEST SIGNAL GENERATOR

Timothy M. Hughes

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	SEPTEMBER 2000	In-House Tech Memo, Jun 00 - Aug 00

4. TITLE AND SUBTITLE

A Graphically Based Test Signal Generator

5. FUNDING NUMBERS

C: N/A
PE: 62702F
PR: 459E
TA: 15
WU: 2F

6. AUTHOR(S)

Timothy M. Hughes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AFRL/IFEC
32 Brooks Road
Rome NY 13441-4114

8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-IF-RS-TM-2000-3

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFRL/IFEC
32 Brooks Road
Rome NY 13441-4114

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

AFRL-IF-RS-TM-2000-3

11. SUPPLEMENTARY NOTES

AFRL Project Engineer: Andrew Noga, (315) 330-2270

12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A digital test signal generator has been developed in the Mathwork's MATLAB environment, to allow for evaluation of the Adjustable Bandwidth Concept Algorithm, U.S. patent #5,257,211. The signal generator incorporates a graphical user interface for the optional graphical placement of signals on the time-frequency signal display. Signal components include tones, binary phase shift keyed signals, band limited gaussian noise and additive white gaussian noise. Some enhancements to the detection algorithm implementation are also described.

14. SUBJECT TERMS

Digital Test Signal, Test Signal Generator, Adjustable Bandwidth Concept, Signal Energy Detection, Graphical User Interface

15. NUMBER OF PAGES 36

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLAS	UNCLAS	UNCLAS	UL

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1.0 Introduction

This report summarizes the work performed under the 2000 Summer Engineering Aide program in the area of signal detection and parameter estimation. The task was to update an implemented MATLAB-based automated signal energy detector, which is described in the In House Technical Memorandum AFRL-IF-RS-1999-6, and to develop and implement a MATLAB-based signal generator, called the Test Signal Generator (TSG). The automated signal detector is based on the Adjustable Bandwidth Concept (ABC) Signal Energy Detector, U.S. Patent #5,257,211. Previous work on this detector was completed in the 1999 Summer Engineering Aide program. Components of this detector that had not been completed were finished prior to the development of the TSG. These updates included an output display, low pass filter delay adjustment, low pass filter window adjustment, and a detection process.

The Test Signal Generator was developed to produce signals that could be processed by the ABC detector. By constructing signals with components of known parameters, the future automated detection by the ABC detector can be verified. Without knowing the exact parameters of a signal, the performance of the ABC detector cannot be properly assessed. The TSG allows for the testing and calibrating of the ABC detector, which is an integral part of the automated signal detection process.

2.0 Background

The ABC algorithm is run through a graphical user interface that was developed and implemented prior to this summer's work. This interface is user-friendly, and is designed to allow for easy alteration of device parameters, thereby facilitating tests of the algorithm. The interface allows full control over all relevant variables, as well as easier manipulation of variables after running the algorithm on a file. All of this leads to a simpler and more adjustable process to analyze a file with the ABC detector. The output display adds the ability to analyze output graphically, as well as the function of comparison of images and image adjustment. All of this functionality will hopefully lead to an easier and more accurate automated detection process.

2.1 Previous Work on Adjustable Bandwidth Concept

The previous work that was done on the Adjustable Bandwidth Concept detector is fully documented in the In House Technical Memorandum AFRL-IF-RS-TM-1999-6, but will be briefly overviewed. This work includes an enhanced implementation, and a graphical user interface.

2.1.1 Enhanced Implementation

The enhanced implementation of the ABC detector includes parameter adjustment, directory structure, and the implementation of a graphical user interface. The parameter adjustment allows for flexibility and more accurate results by altering the number of stages, the number of N-point delays that each stage uses, and the filter coefficients for each stage. The directory structure has two principle objectives. The first is to organize the contents and accessories to the ABC algorithm. This resulted in sensible organization and ease of code maintenance. The second objective of the structure is to ease the running of the algorithm. Relevant variables are stored together, allowing ease of loading and further enhancements.

2.1.2 Graphical User Interface

The graphical user interface (GUI) designed for the ABC detector has two principle objectives. The first objective is to make the algorithm a user-friendly program. The GUI makes the algorithm much more efficient, and increases productivity while easing the usage. Having a screen with buttons and menus to interact with is more desirable than having to change the actual code. The visualization of the algorithm's block diagram and active controls also lends in comprehending the system. The second objective is to utilize all of the enhanced implementation's flexibility. The GUI organizes, displays, and accesses all of the variables used in adjusting the parameters and settings for the algorithm. This GUI is a very powerful enhancement, and it plays a very integral part in comprehending and using the ABC detector.

2.2 Updates to the Adjustable Bandwidth Concept

The first objective of this summer's work was to update the ABC detector with enhancements that had not been completed yet. These updates were needed in order to get the full benefit of the ABC detector algorithm and GUI. These updates included delay value adjustment, low pass filter adjustment, detection processes, and an output display.

2.2.1 Delay Value Adjustment

The GUI for the ABC detector contains a button labeled "Delay", which now has the ability to change the number of N-point delay segments for each stage. Pushing the button will open a new window, which shows the current number of delays for the stage, as well as the filter response. Also displayed is the current filter length and Fast Fourier

Transform (FFT) length. Below the filter response is a scroll menu that allows a new delay value to be chosen. This list of choices is upper limited by the current delay value of the previous stage and lower limited by the current delay value of the next stage. The first stage is allowed a maximum value equal to the number of frequency bins, and the last stage is allowed a minimum value of zero. If a new delay value is chosen, the filter response is adjusted accordingly. If a new value is chosen and the "Done" button is pressed, the delay value for the current stage is changed and saved. If the "Cancel" button is pressed, any actions taken in the window will be disregarded and the delay value will be set to the value it was upon entering the "Set Low Pass Filter Delay" window. A figure showing this window is displayed below.

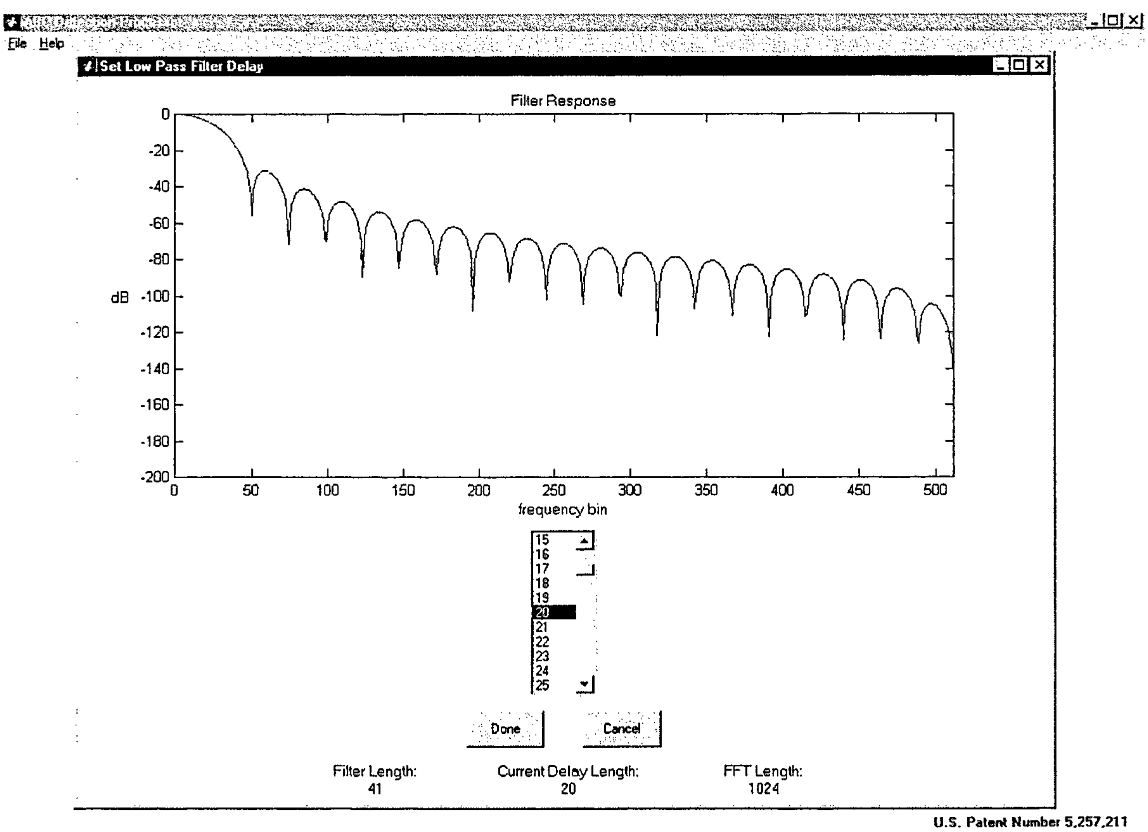

Figure 2.2.1-1 Low Pass Filter Delay Selection Screen

2.2.2 Low Pass Filter Adjustment

The GUI for the ABC detector also contains a button labeled "LPF", which now has the ability to change the low pass filter window for each stage. Pushing the button will open a new window, which shows the current filter, the number of delays, the FFT length, and the filter length. Also displayed are three radio buttons, each with a different filter window type label. Clicking a radio button will change the filter window for the current stage to the appropriate type, adjusting the filter response accordingly. If changes are made and the "Done" button is pressed, changes are saved. If the "Cancel" button is pressed, the filter window for the current stage is set to the type it was when the "Set Low Pass Filter Window" was opened. A figure showing this window is displayed below.

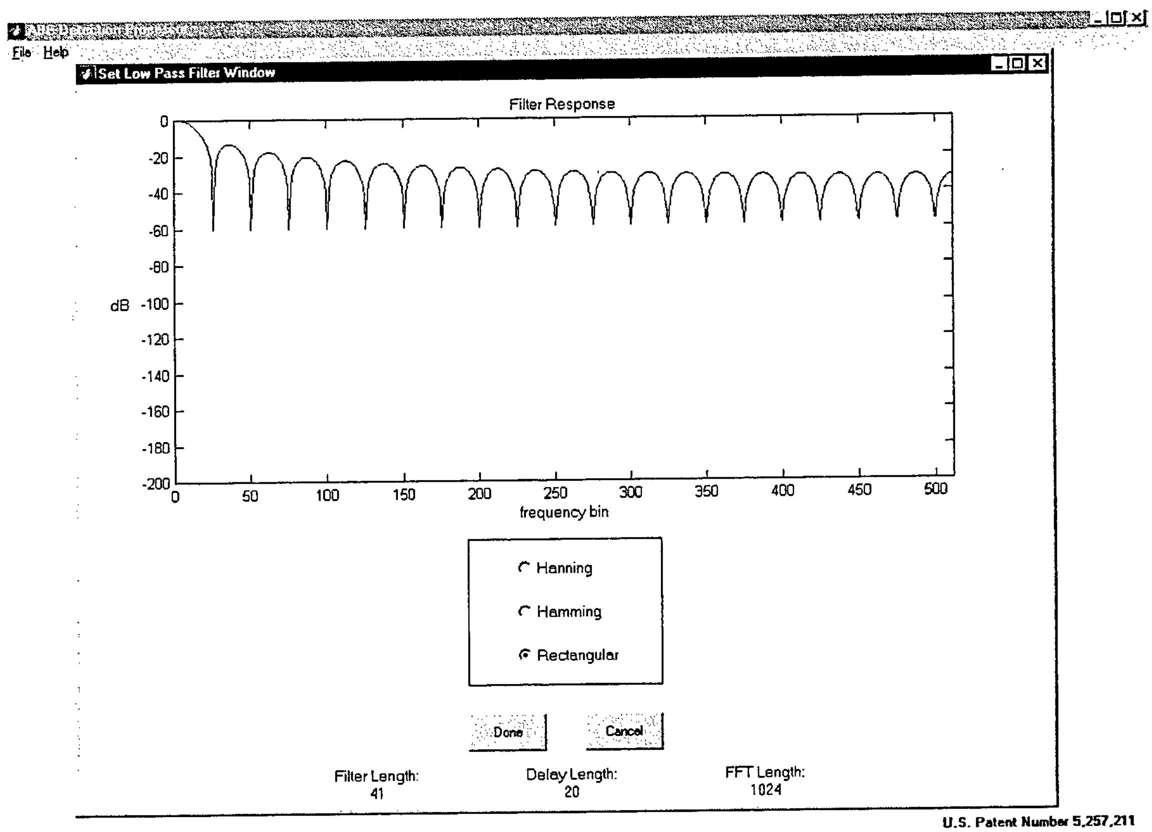

Figure 2.2.2-1 Low Pass Filter Window Selection Screen

2.2.3 Detection

The GUI for the ABC detector also contains a button labeled "Detector", which now has the ability to change the detection thresholds for each stage, but only after processing the signal with the algorithm. Pushing the button will open a new window, which shows the current threshold values for each available stage and the noise floor estimate. Pressing the "Default" button will reset the threshold values and run the detection on the processed signal. Pressing the "Done" button will process the current thresholds, and pressing the "Cancel" button will discard changes and set the values to their values upon opening the window. A figure showing this window is displayed below.

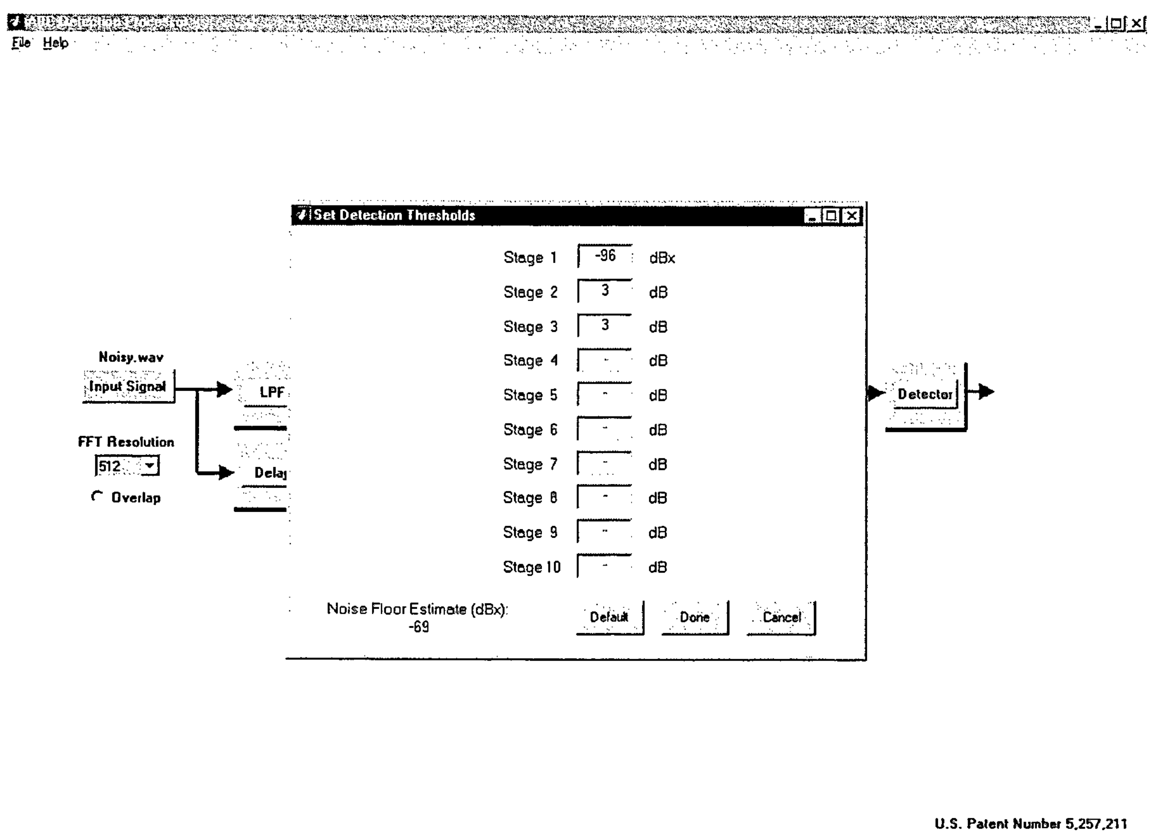

Figure 2.2.3-1 Detection Threshold Selection Screen

2.2.4 Output Display

A major update to the ABC detector was an output display. After the algorithm runs the given system, its output consists of time vs. frequency images of the input, output, and detection for each stage. These spectrograms are what the user analyzes after running the algorithm. Using these images, the signal is broken into components, ranging in frequency from wide band to narrow band. The output display has many characteristics that are practical and useful.

The first characteristic of the output display is that it has two display images on the screen. This allows for comparison of any two images that the user may be interested in. Different stages can be compared to the input, as well as each other. Also, post-detection and pre-detection images can be compared, which is often useful in analyzing data.

Another characteristic of the output display is its ability to alter the images. Both of the images have a slide bar on the right side, parallel to the frequency axis. These bars alter the scaling of the images. As they are labeled, sliding the bar up will weight the higher intensity values more than the lower, causing a decrease in signal presence. Sliding the bar down will increase the weight on the lower intensity values, making them stand out more. Both cases are useful in different situations, depending on the signal and the images. If there were certain components a user is interested in, they would want to make them stand out more. Alternately, if there are components a user does not care about, their weight can be decreased. Another ability the output display has in altering the image is in changing the colormap (mapping of values in an image to colors) by means of the "Colormaps" menu. Different colormaps are useful in different situations, similar to the slide bars used for scaling. The contrast of a colormap will accent certain signal qualities, while masking others. Their use depends on the signal, as well as the user's tastes. Examples of the ABC detector output display can be found in Appendix A.

3.0 Overview of the Test Signal Generator (TSG)

The Test Signal Generator (TSG) was developed in order to construct signals to be processed by the ABC detector. These signals are constructed in a way such that their components and related parameters are known. When these signals are then processed, the data acquired from the ABC detector can than be compared to the signal's known composition. The construction of signals using the TSG is done in two ways, either by manual parameter entry, or graphical placement. The graphical placement is advantageous in the sense that it allows precision placement of a component on the actual spectrogram, which is the basis of the ABC detector. This allows the user to become familiar with this display type, as well as save time and effort in placing components in desired locations. This construction is accomplished using a graphical user interface and various signal components.

3.1 Signal Components

The signal components of the TSG include tones, binary phase shift keyed (BPSK), additive white Gaussian noise (AWGN), and band limited Gaussian noise (BLGN). These components can be combined to construct any type of signal with these forms of components. Each component has its own related parameters, and can be altered or adjusted to meet the user's needs. After each new component is added, the signal amplitude levels are displayed. These levels must remain between negative and positive one in order to refrain from clipping when writing the wave file.

3.1.1 Tones

One of the components of the TSG is a tone. This component consists of three parameters. These parameters are amplitude in dB full scale, frequency in radians, and phase shift in degrees. The tone is then calculated by the equation:

Tone = 10^(amplitude/20) * cosine (frequency * time + phase)

This tone component then gets added to the total signal equation, which depends on the components already present in the total signal.

3.1.2 Binary Phase Shift Keyed (BPSK)

Another component of the TSG is a BPSK signal. This component consists of five parameters. These parameters are bits per second, samples per bit, samples per carrier cycle, carrier frequency in radians, and amplitude in dB full scale. With these variables, the other needed parameters can then be calculated, which include number of bits (duration of signal * bits per second), number of samples (number of bits * samples per bit), and samples per bit (sample rate / bits per second). With these values, the following equations can be solved to produce the desired BPSK signal:

Carrier = 10^(amplitude/20) * sin (carrier frequency * time)

$$\text{Bitstream} = \text{sign (rand (number of bits,1)} - 0.5)$$

$$\text{BPSK} = \text{kron (Bitstream,Carrier)}$$

The function "rand(X,1)" in MATLAB chooses uniformly random distributed numbers on the range 0.0 to 1.0, and produces an X-by-1 matrix of these numbers. The function "sign(X)", for each value of X, returns a value of one if its value is greater than zero, zero if its value equals zero, and negative one if its value is less than zero. The function "kron(X,Y)" produces the Kroneker tensor product of X and Y, which results in a matrix consisting of all possible products of the elements in X and Y. With these variables, equations, and functions, the BPSK signal is generated in the TSG.

3.1.3 Additive White Gaussian Noise (AWGN)

Another component of the TSG is Additive White Gaussian Noise. This component consists of only one parameter. This parameter is noise strength in dB full scale. The AWGN is then calculated by the equation:

$$\text{AWGN} = 10\text{\^{}(noise strength/20)} * \text{randn (size (total signal))}$$

The function "randn(X)" in MATLAB produces and N-by-N matrix of normally distributed random numbers, with a mean of zero and a variance of one. The state of the random number generator is reset by using the "clock" function, which returns the time of the system, so that the random number sequences are unique every time the AWGN component of the TSG is generated.

3.1.4 Band Limited Gaussian Noise (BLGN)

The last component of the TSG is Band Limited Gaussian Noise (BLGN). This component consists of four parameters. These parameters are noise strength in dB full scale, order of the pass band filter, and the lower and upper boundaries of the pass band for the filter. The BLGN is then calculated by the equation:

$$\text{b coefficients} = \text{fir1 (order , [lower bound + eps} \quad \text{upper bound} - \text{eps])}$$

$$\text{BLGN} = \text{filter (b coefficients, 1, AWGN)}$$

The function "fir1(N,X)" in MATLAB designs an N'th order lowpass FIR digital filter and returns the filter coefficients. The constant "eps" is used as the default tolerance, and it is used so that values of zero and pi may be entered as the boundaries. The function "filter(X,Y,Z)" filters the data in vector Z with the filter described by vectors X and Y to create the filtered data, BLGN.

3.2 Adjustable Parameters

The TSG allows for multiple parameters to be adjusted in order to make a system fully customizable. These parameters are adjusted by using the GUI. Any of the parameters that may be adjusted can be done so by pull down menu, edit box, or radio button. These appear on the bottom of the GUI layout. The parameters that can be adjusted include sample rate, overlap, Fast Fourier Transform size, the number of bits, and the duration of the signal in seconds. The change in the spectrogram, though, will not be present until the image has been updated.

The sample rate can be changed by a pull down menu. This menu includes various common sample rate values, as well as the ability to enter any other value by choosing "Other". This opens another window that allows for any value within the range of 100 and 65536 Hz to be entered and saved as the new sample rate for the current signal generation.

The time segment overlap of the system can be turned on or off with the radio button on the GUI labeled "Overlap". If the button is highlighted, the system will be processed with an overlap of fifty percent. If the button is not highlighted, the system will be processed with no overlap.

The Fast Fourier Transform size for the current system can be changed by a pull down menu. The current value is the value displayed in the box. Selecting one of the values from the list can change the FFT size. This change is automatically stored upon selection.

The number of bits can also be changed by selecting a value from the associated pull down menu. The value can be either eight or sixteen bits. This change is stored automatically upon selection.

The edit box on the GUI can adjust the duration of the file, in seconds. This box displays the current duration value for the signal. If a number is entered for the new duration, it is automatically stored. If the new duration is shorter than the previous duration, the signal is truncated, losing any information stored beyond the new duration point. If the new duration is longer, the interval between the two will be blank, unless AWGN has been added. In that case, the AWGN will fill to the end of the new signal duration.

3.3 Implementation

The Test Signal Generator was developed with the graphical user interface as the base. One of the objectives of the TSG was to have a straightforward way to generate signals that was not time consuming. This GUI implementation allows the generation of multi-component signals to meet this objective. There is a plot area, where the spectrogram of the current signal is displayed, and there are file menus, pull down menus, buttons, edit boxes, and radio buttons on the GUI that allow for control over the signal generation. The implementation contributes to the understanding of the procedure to generate test signals. It also allows for access and adjustment to all parameters relevant to the system.

3.3.1 Graphical User Interface Layout

The Graphical User Interface layout is designed to run from one main screen. This screen contains the spectrogram of the current signal, as well as controls to add multiple components and set multiple parameters. This screen has five buttons on the left side of the plot that perform main functions. The top four add components to the signal, and they include "Tone", "Band-Limited Noise", "BPSK", and "Noise". The bottom button clears the entire signal that has been generated, and is labeled "Clear". Below these buttons are two more buttons that are lined up parallel to the time axis. The first, "Undo Signal", will subtract the last addition of a component from the total signal. If no components have been added, or if the last component has already been removed, the button is not active, and is shaded out accordingly. Next to this button is another, labeled "Update Image". This button will update the spectrogram with any changes that are not yet included. If any components are added or parameters changed, the new signal will not be displayed until this button is pressed. Also on the screen are file menus, pull down menus, buttons, edit boxes, and radio buttons. These control the adjustable parameters. Values changed in the objects are saved to the value entered.

The image below shows the GUI layout of the TSG. The blank plot area is the place the spectrogram of the signal would be displayed upon generation. The buttons on the left side of the display are the component buttons, while the various objects below this display area are the parameter adjusting objects.

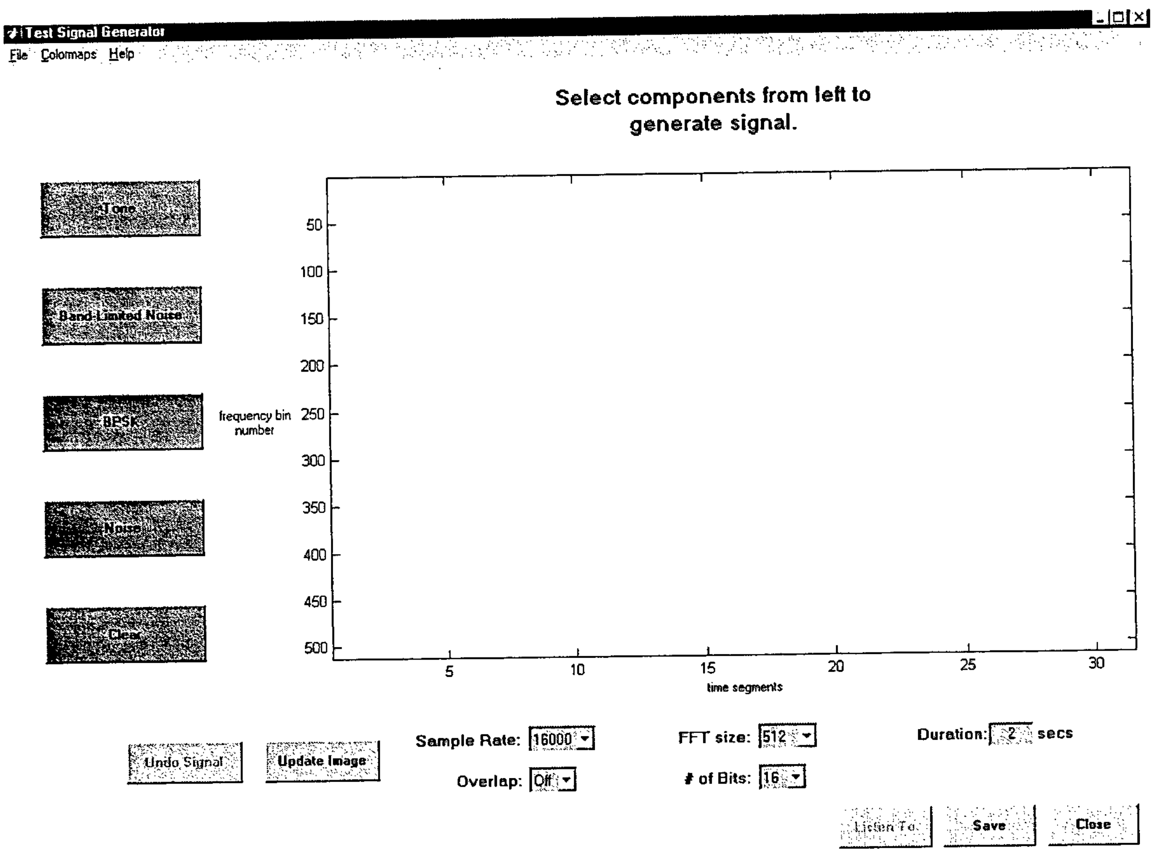

Figure 3.3.1-1 Test Signal Generator Graphical User Interface Layout

3.3.2 Test Signal Generator Procedures

Upon running the Test Signal Generator, the main window will be displayed. To add components to the signal being generated, one of the four buttons labeled by the component types must be pressed. If a BPSK signal is desired, it must be added first. Since the BPSK may alter the sample rate, all other components must be added to the generation after it has already been chosen. Pressing one of the component buttons will open a new window, which will contain objects enabling parameters for each component to be set.

In each window, excluding the AWGN, the option of graphical placement is available. If the "Graphical Placement" button is not chosen, the parameters must be entered manually. If the button is chosen, certain parameter entry objects will be inactive. This is due to the fact that some parameters will be calculated from the placement of the box drawn on the spectrogram. Independently of this choice, some parameters must be entered in this window. When parameters are set to their desired values, either the "Place Signal" button, if graphical placement, or "Done" button should be pressed to add the signal. The "Cancel" button will disregard any changes. If graphically placing, drag the mouse cursor on the spectrogram screen to place the signal for desired location and parameters.

After adding desired components to the generation, there are three options for the signal. One option is to hear the signal. Pressing the "Listen To" button will play the file, given your system has sound, and can be done any time there is at least one component present in the generation. The second option is to save the generated signal as a wave file. Pressing the "Save" button will open up a window where the current file can be saved in any desired directory, with the extension of *.wav. Another option is to press the "Close" button, which will close the TSG without saving the file or work done since last saving. Any files saved before pressing this button will still be saved.

The file menus at the top of the screen have three options. One option is to open the "About" window in the "Help" menu, which gives information about the TSG. Another option is the "Colormaps" menu, which will allow changing of the spectrogram image, both colors and contrast. The last option is the "File" menu. This menu allows you to close the TSG, similar to the "Close" button. No changes are saved.

4.0 Conclusions

The updates to the Adjustable Bandwidth Concept Signal Detector meet the expectations of what was planned previously for future developments. The functionality and practicality are both as planned. The updates add abilities that were needed to utilize the algorithms full capabilities. As such, the implementation of the ABC detector was improved as hoped for.

The Test Signal Generator was developed into a successful digital signal generation tool. This signal generation tool will play an important role in calibrating and testing the ABC detector. Its flexibility and capability are both enhanced by the graphical user interface developed to run the TSG. This interface proved easy to use and maintain throughout development and testing.

4.1 Future Developments

Although the Test Signal Generator and its graphical user interface are capable of generating useful signals in a direct and accurate manner, there is a major future development that would enhance this digital signal generator. This development would be a textual representation of the generated signal's components and relevant parameters. This output would accompany the graphical representation, and would include all components and each component's key parameters. This output would also lend in pinpointing each component and aide in gauging the accuracy of the ABC detector's automated signal detection functions.

4.2 Acknowledgements

The updates to the enhanced implementation of the Adjustable Bandwidth Concept algorithm and development and implementation of the Test Signal Generator could not have been possible without the guidance and support of Dr. Andrew Noga. His guidance lead to the author's current understanding and proficiency of programming in MATLAB, and his support and resources aided in the knowledge needed to exploit its capabilities. His ideas also lead to the layout of the graphical user interface for the TSG. Gratefulness is also due for the opportunity to participate in the Summer Engineering Aide Program at the Information Directorate, Rome Research Site.

Appendix A:

Test Signal Generator Processed Output

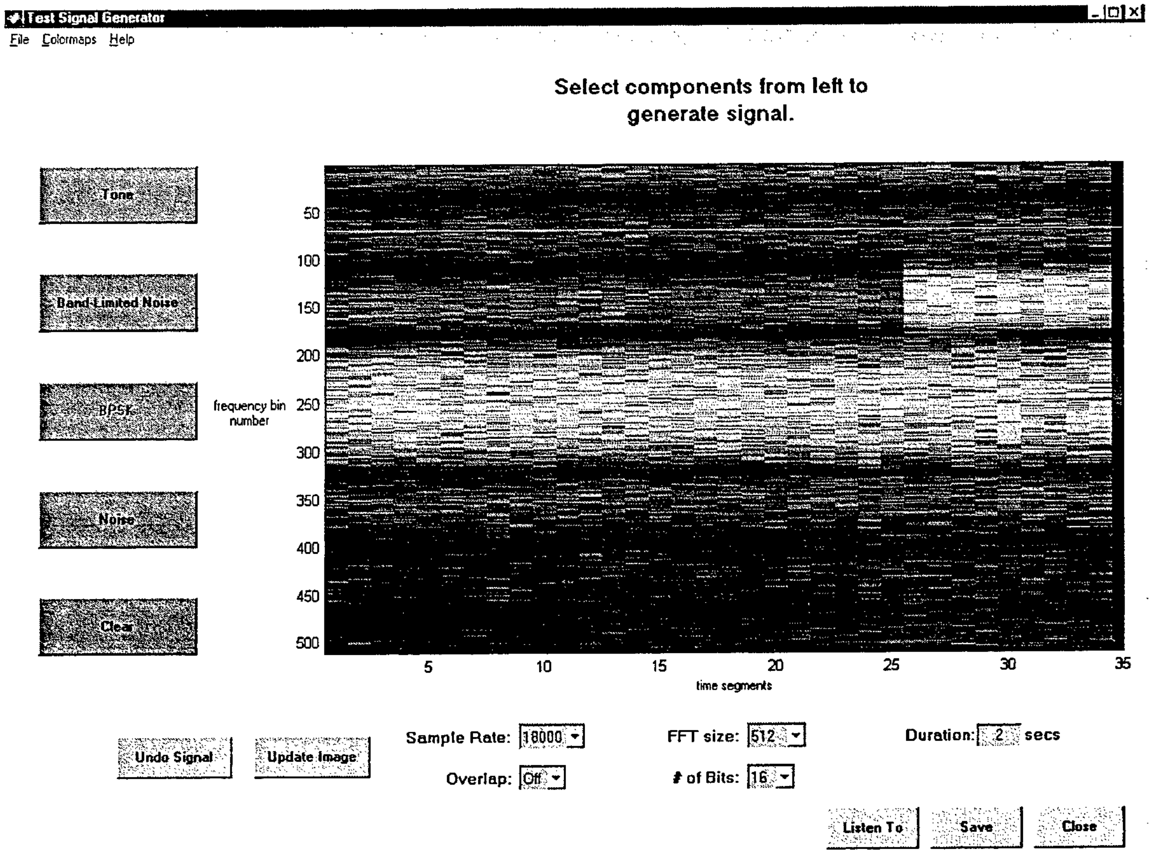

Figure A-1 Test Signal Generator Displaying Generated Signal

The above image (Figure A-1) is the GUI layout of the TSG after generating a signal. This signal includes a graphically placed BPSK signal, graphically placed BLGN, and a graphically placed tone. The BPSK signal has an amplitude of -30 dB full scale, order of 64, and was placed between frequency bin number 200 and 300 for the entire duration. The BLGN has a noise strength of –20 dB, and was placed between frequency bin numbers 100 and 175 in the last 10 time segments. The tone has an amplitude of –10 dB, a phase of 0 degrees, and was placed near frequency bin 70 for the entire duration. The parameters shown on the screen include the following: sample rate is 18000 Hz, overlap is off, FFT size is 512, number of bits is 16, and duration is 2 seconds. This file is saved as Summer_00_Example.wav.

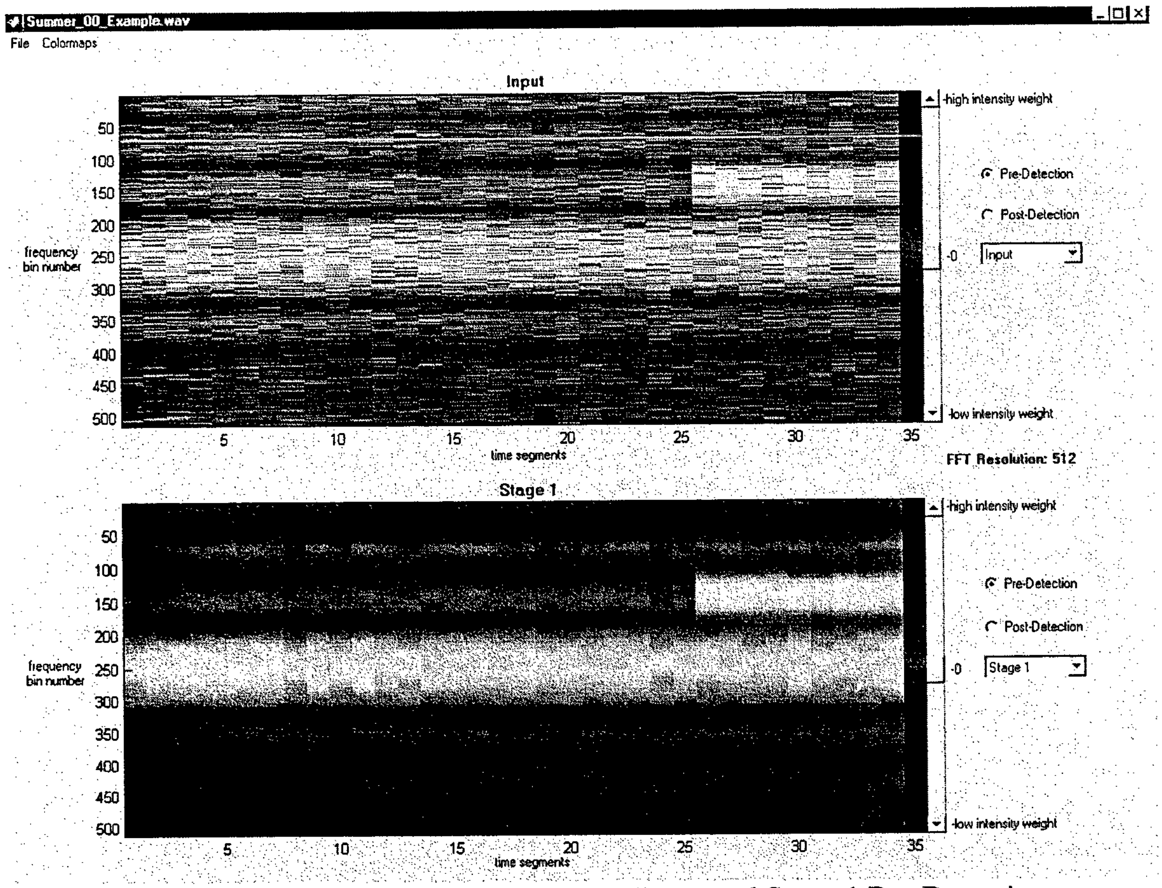

Figure A-2 Summer_00_Example.wav Input and Stage 1 Pre-Detection

The above image (Figure A-2) is the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system, which should look identical to the representation shown in the TSG. The lower image is the first stage pre-detection output, which is the wide band component of the signal. The first stage pre-detection should have a smoothing effect, and should only display wide band components. This image shows that the tone, which is a narrow band component, has been removed from the first stage.

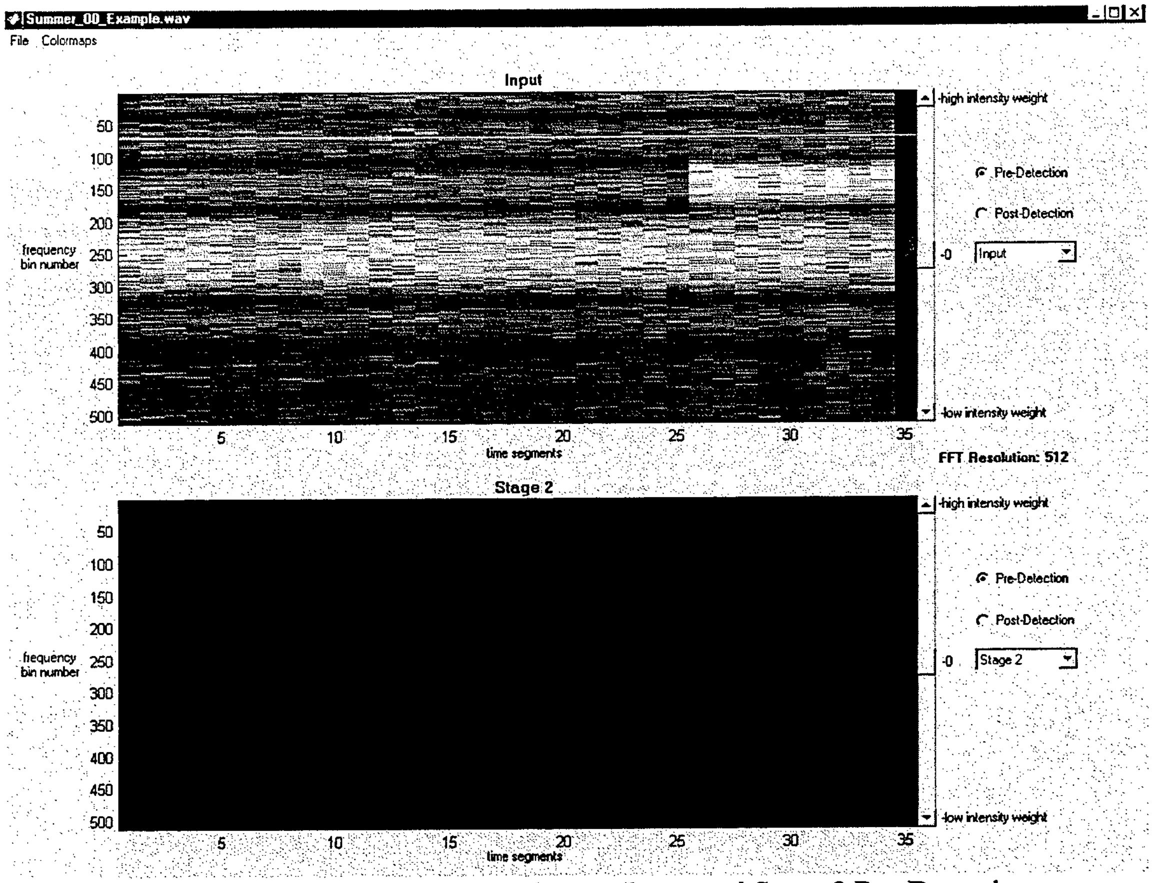

Figure A-3 Summer_00_Example.wav Input and Stage 2 Pre-Detection

The above image (Figure A-3) is again the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system, while the lower image is the second stage pre-detection. The second stage pre-detection should have only medium band components present. This image shows the tone very faintly, but also shows how the wide band component has been successfully removed.

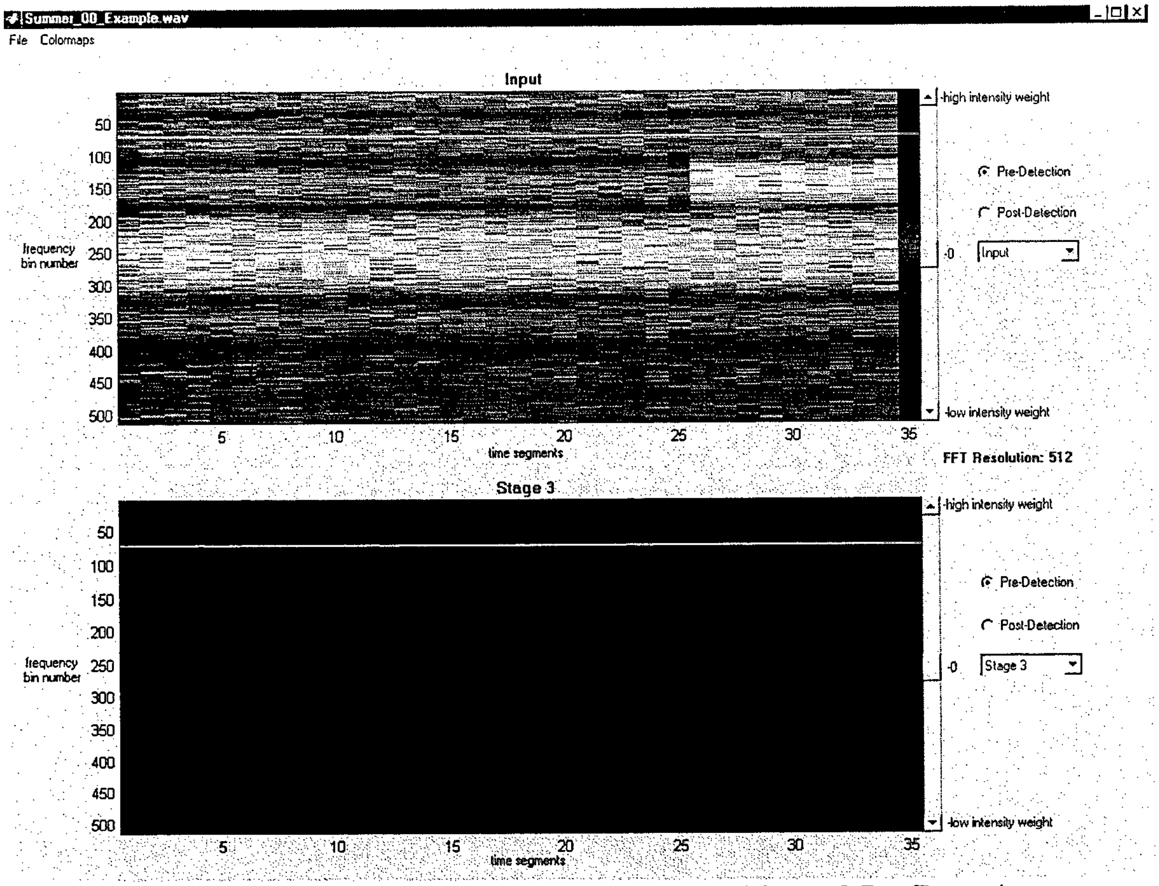

Figure A-4 Summer_00_Example.wav Input and Stage 3 Pre-Detection

The above image (Figure A-4) is again the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system, while the lower image is the third stage pre-detection output. The third stage pre-detection should have only narrow band components present. This image shows the tone, and also shows how the wide band and medium band components have been successfully removed.

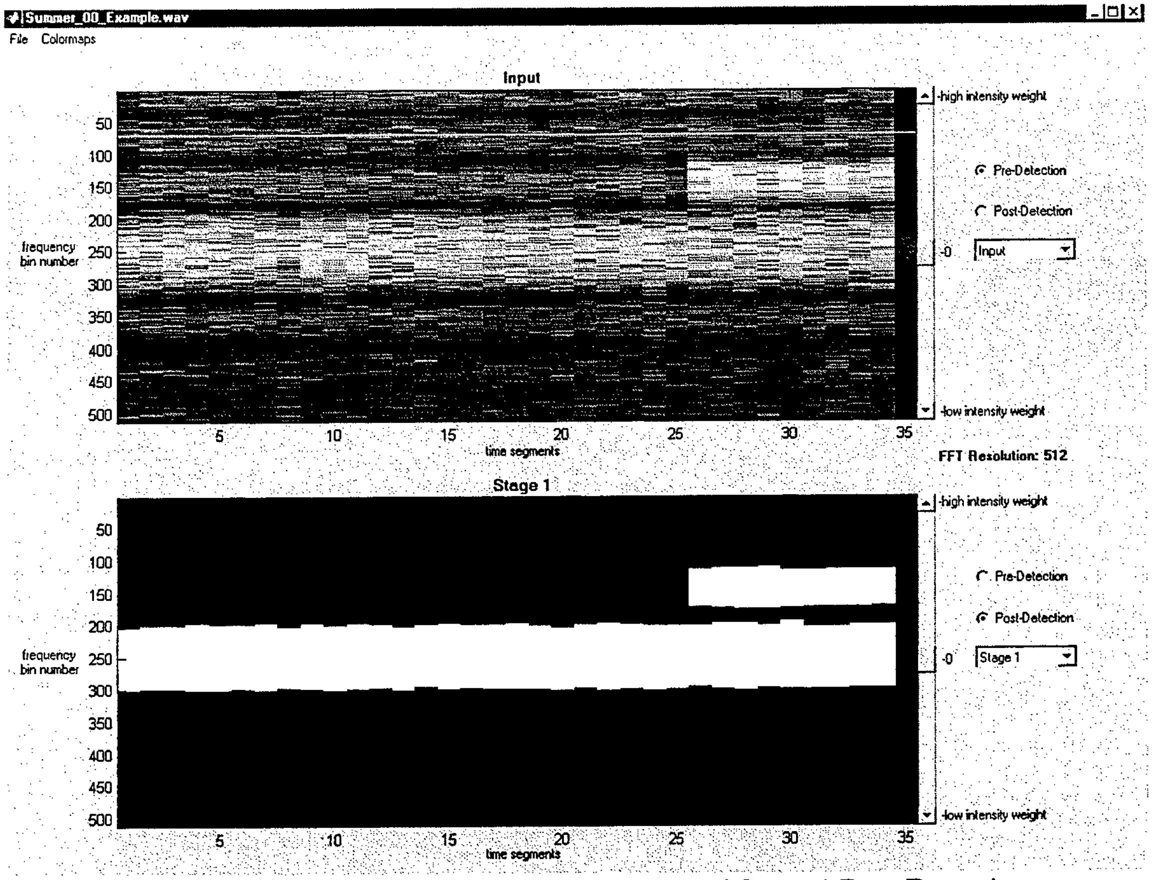

Figure A-5 Summer_00_Example.wav Input and Stage 1 Post-Detection

The above image (Figure A-5) is the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system, while the lower image is the first stage post-detection output, which is the wide band component of the signal. The areas that are detected are the main lobe of the BPSK signal and the BLGN that was added near the end of the signal. This first stage had a detection threshold that was set at -66 dBx.

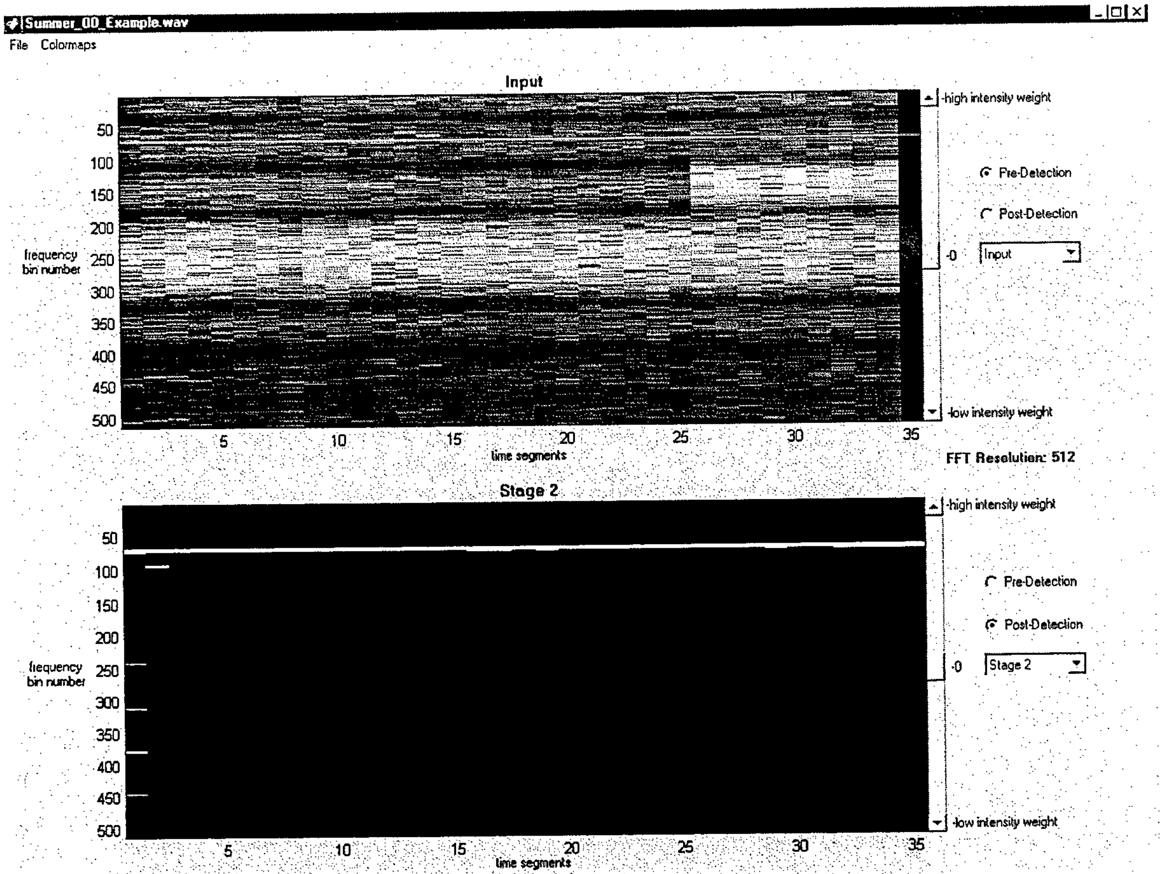

Figure A-6 Summer_00_Example.wav Input and Stage 2 Post-Detection

The above image (Figure A-6) is again the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system. The lower image is the second stage post-detection output, which is the medium band component of the signal. The area that is detected is the tone that was added across the entire duration. There are also some detections at the beginning of the file due to time averaging and lack of enough segments to average. This second stage had a detection threshold that was set at 3 dB.

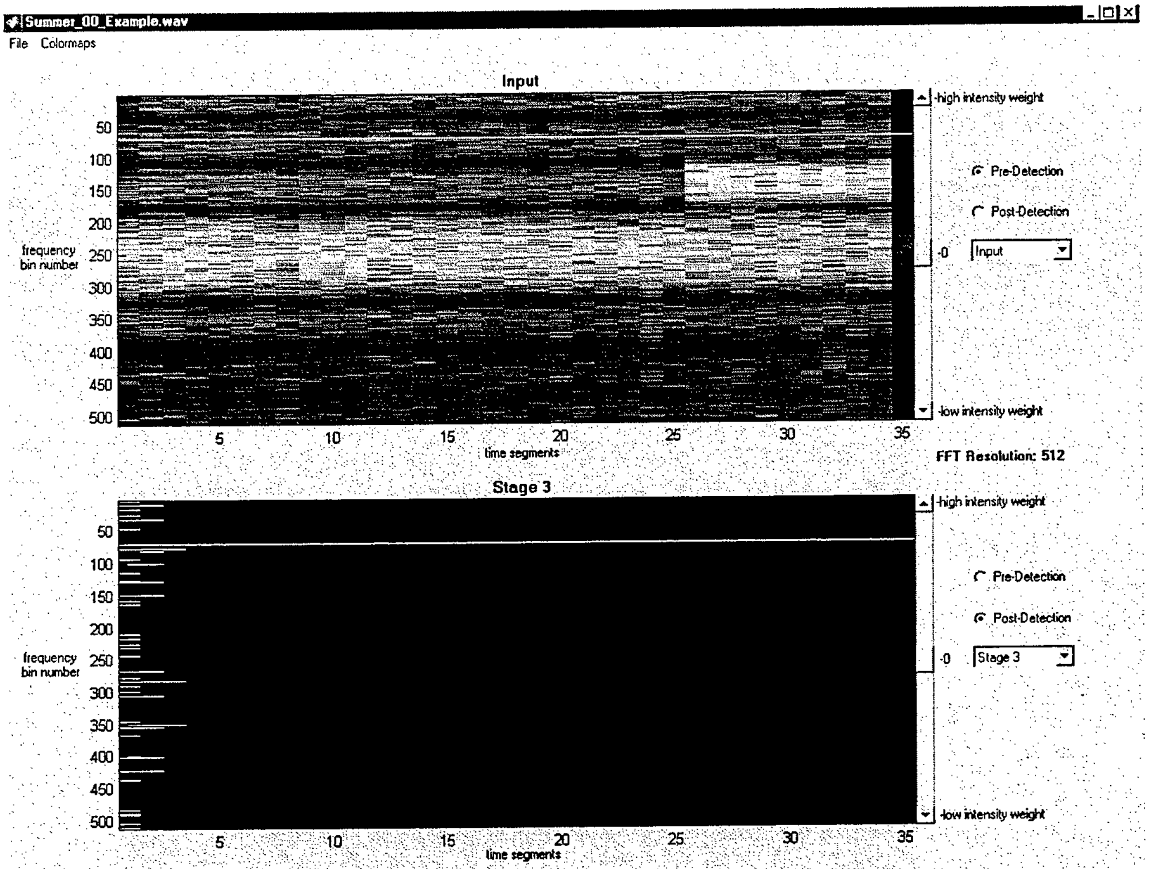

Figure A-7 Summer_00_Example.wav Input and Stage 3 Post-Detection

The above image (Figure A-7) is again the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system. The lower image is the third and final stage post-detection output, which is the narrow band component of the signal. The area that is detected is the tone that was added across the entire duration. There are also more abundant false detections at the beginning of the file due to more time averaging and lack of enough segments to average. This third stage had a detection threshold that was set at 6 dB, and is able to more accurately locate the tone that was also detected in the second stage.

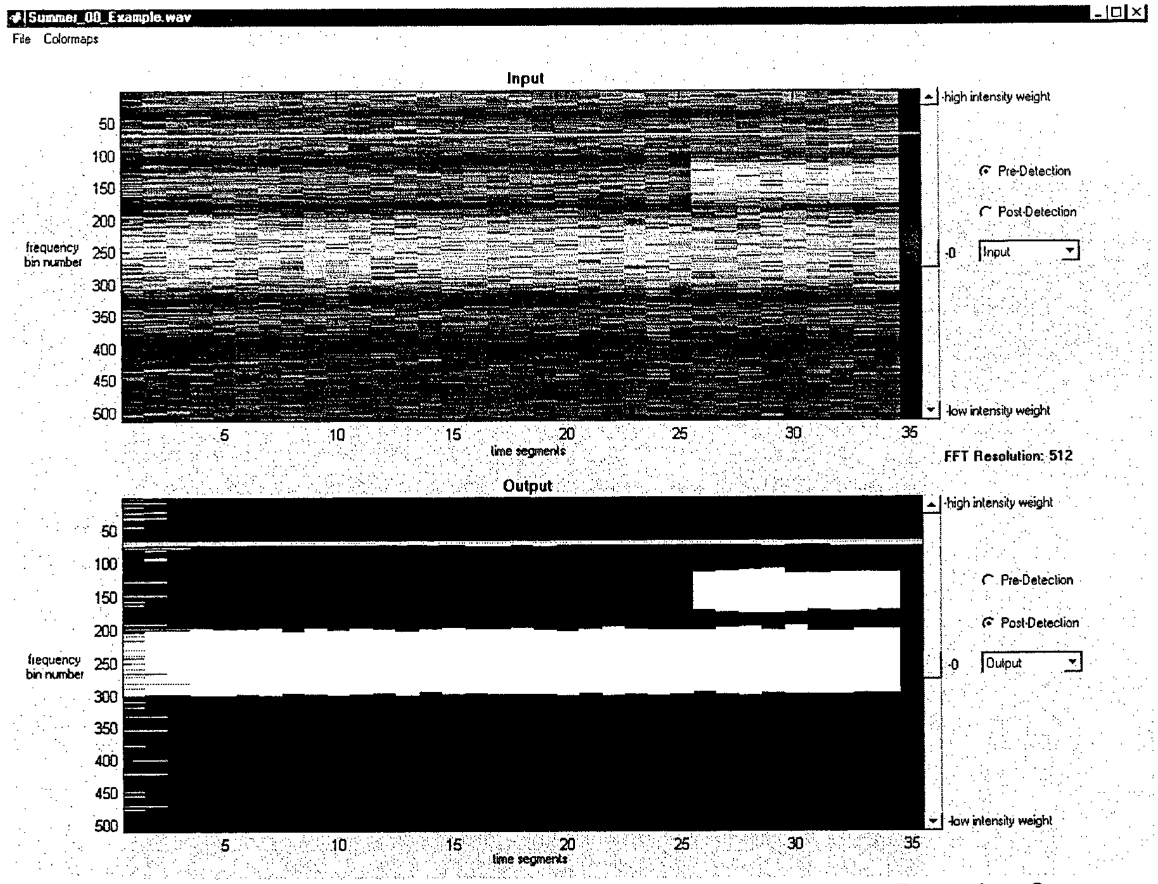

Figure A-8 Summer_00_Example.wav Input and Composite Post-Detection Output

The above image (Figure A-8) is again the output display from the Adjustable Bandwidth Detector. The upper image is the visual representation of the input to the ABC system. The lower image is the composite post-detection output, which includes the narrow band, medium band, and wide band components of the signal. The areas that are detected include each of the individual stage detections. All detections are represented by a different color, and they are overlaid to create a composite image.

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